INTER-ANNUAL VARIATIONS OF LAND COVER IN AND AROUND MAROUA, NORTHERN CAMEROON

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Abstract Land degradation is progressing on the Earth. Such degradation results from various factors, including climatic variations and human activities. We studied inter-annual variations of land cover around Maroua, Northern Cameroon using Landsat MSS data in order to evaluate a degree of land degradation. The results of this study are summarized as follows: (1) We found increases in area of bare land and cultivating land, and a decrease of biomass in savanna vegetation after 1973. These features show a progress of land degradation in the study area. (2) The degradation trends correspond to climatic fluctuation. Especially, area of bare land correlates closely with annual rainfall. (3) About 100 km^2 of the study area shows irreversible degradation between 1973 and 1987.

Key words: land degradation, inter-annual variations, land cover, Landsat MSS, Cameroon

1. Introduction

In recent years, land degradation, including reduced biological productivity and bare land expansion, has been progressing in various places in tropical semi-arid areas due to fluctuations in precipitation and the intensification of human activities. This further reduces the productivity of land in these areas that is already infirm, thereby aggravating difficulties in producing enough food to sustain ever-increasing populations.

Although land degradation can be confirmed by ground surveys, it is not easy to grasp its spatial expanse. On the other hand, satellite image data transmitted from Landsat, NOAA and SPOT can provide periodic ground information, covering a wide area. Thus, extensive, highly accurate information can be obtained by combining the

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results of analysis of such satellite image data with data obtained by field surveys conducted in situ.

In this study, the authors examined the land cover in and around Maroua in northern Cameroon, and explicated its inter-annual variations, using Landsat MSS data monitored in four different years between 1973 and 1991.

2. Study Area

The area selected for analysis extends approximately 60 km square from south to north, and includes Maroua (lat. 10° 35' N., long. 14° 20' E.), a major city of northern Cameroon (Fig. 1). The surface of this area gently inclines from west to east; the

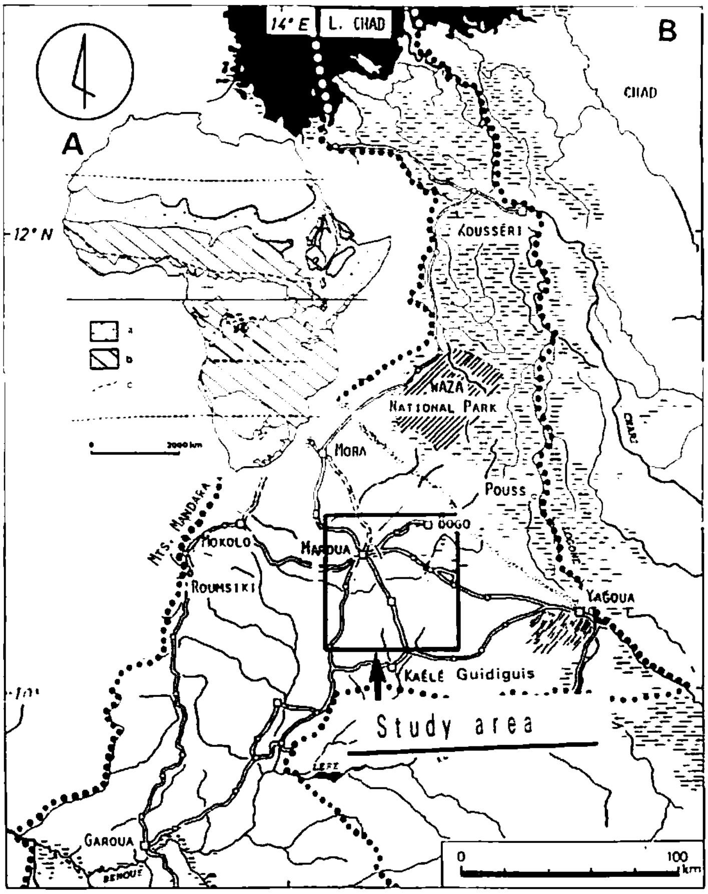

Fig. 1 Study area (from Kadomura, 1989)
A: Cameroon (a: tree and shrub steppes, b: savannas, c: limit of former extent of rain forest)
B: Northern Cameroon

typical features of this area are inselbergs represented by a rocky mountain on the north side of Maroua, and pediments or gentle slopes around them. Vegetation in this area is on the boundary between steppe and savanna (Fig. 1A).

The climate is typical savanna, with clear distinction between the rainy (April to October) and dry (November to March) seasons. The annual mean temperature is 28°C, and the annual mean precipitation is about 900 mm (Jeune Afrique, 1980).

Maroua is situated at the top vertex of the triangular-shaped nation of Cameroon. Due to its proximity to Nigeria in the west and Chad in the east, Maroua has been thriving as a commercial city; the population reached about 400,000 in 1986 (Criaud, 1987). Agricultural crops include cotton and staple foods, such as sorghums and millets which are grown on the alluvial plain of the Tsanaga River running through the center of the city from west to east and on gentle slopes of piedmonts. During the dry season, vegetables including carrots, onions, tomatoes and okras are cultivated by irrigation in the flood plain of the Tsanaga River. Stock-farming is more extensive than cultivation, and includes grazing of cattle, sheep and goats.

The people of Maroua use firewood and charcoal as fuel; shrubs, mainly acacias, around the city are used for fuel materials.

3. Methods for Analysis and Data Used

The image data used in this study were Landsat MSS images taken in four different years as shown below; they were put to analysis after registration. The path-row of (1) was 198-53, while those of (2), (3) and (4) were all 184-53. The bands used were 4, 5, 6 and 7 (hereafter refered to as MSS 4, 5, 6 and 7).

(1) January 12, 1973: Line 1- 1024, Column 61 - 1084
(2) February 19, 1985: Line 319 - 1342, Column 310 - 1333
(3) January 24, 1987: Line 321 - 1344, Column 260 - 1283
(4) February 4, 1991: Line 370 - 1393, Column 351 - 1374

In order to study inter-annual variations, comparisons were made between the 1973 image taken immediately after the launch of Landsat Satellite, and the 1991 image taken for use in the latest investigation. In addition, the 1985 image was used to study the influence of the drought of 1983-1984, the most serious drought since 1970, while the 1987 image was used to study the changes in land cover conditions due to the subsequent recovery of precipitation.

The months of January and February, when the four satellite images were taken, belong to the dry season. In general, data for the rainy season are required for estimating the amount of natural vegetation cover. However, the authors concluded that the inter-annual variations in land cover could be estimated sufficiently with the data for the dry season alone, since 1) no useful rainy season data were available; 2) the amount of vegetation cover could be estimated to some extent based on the distribution of withered grass; and 3) agricultural activities are mainly concentrated in the dry season.

Field surveys were conducted in November and December, 1988, and in February, 1991.

The analysis procedure is shown in Fig. 2. Using the image data taken on February 4, 1991, when a field survey was being conducted, as the base image for analysis, land cover conditions confirmed in situ were classified by visual interpretations, classification with cluster analysis and the maximum likelihood method. The remaining data were also classified by cluster analysis and the maximum likelihood method using soil exponents as an index (the correlation between MSS 4 and MSS 5) to indicate the degree of vegetation cover of the ground surface for each type of land cover classified using the 1991 data. Then, the inter-annual variations were traced by superimposing the results of the classification of respective image data.

4. Types of Land Cover Conditions and Their Inter-annual Variations

The land cover conditions of the study area were classified into the following seven types. The properties of each type are described below on the basis of a composite image (Photo 1) prepared for visual interpretations by designating MSS 4, MSS 5 and MSS 7 as Blue, Green and Red, respectively.

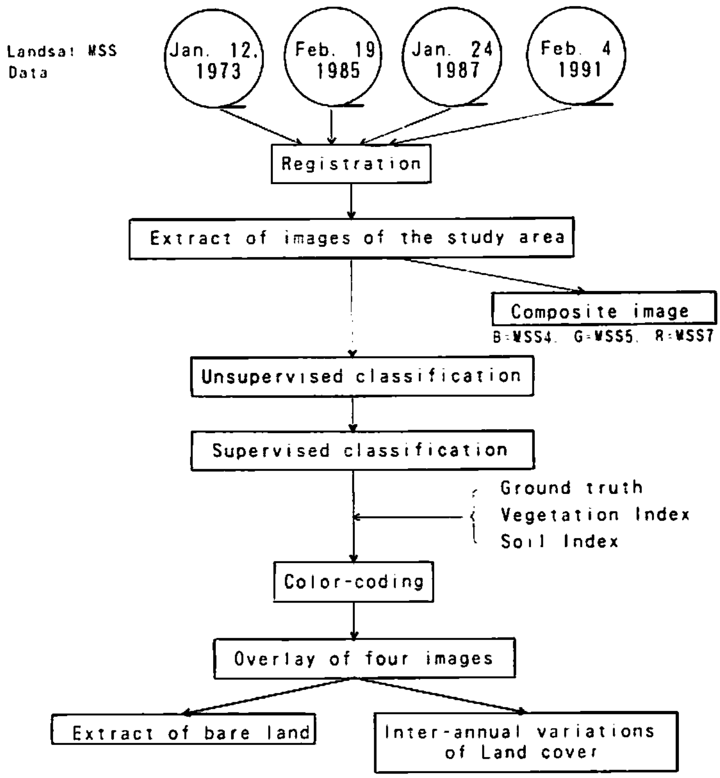

Fig. 2 The procedure of this study

Photo 1 Composite image of study area observed on February 4, 1991 (Blue=MSS4, Green=MSS5, Red=MSS7)

(1) Bare land: Bare land comes out in white in the composite image; river beds that dry up during the dry season fall under this category.

(2) Extremely sparse vegetation cover, and (3) Sparse vegetation cover: These types of land cover represent the natural vegetation in this area; shrubs are observed sporadically during the dry season. They appear either light brown or deep green in the composite image depending on the degree of vegetation density.

(4) Bush: Bush was recognized in the southern part in the 1973 image, as well as around inselbergs in the east-northeast of Maroua in the shape of concentric circles; it comes out dark in the composite image. Bush contains densely-growing shrubs of the acacia family.

(5) Upland fields and pastures: Pastures on the slope of a large inselberg behind Maroua, sorghum fields on the western piedmont, and sorghum and millet fields along the road connecting Maroua and Bogo and along the Tsanaga River are representa-

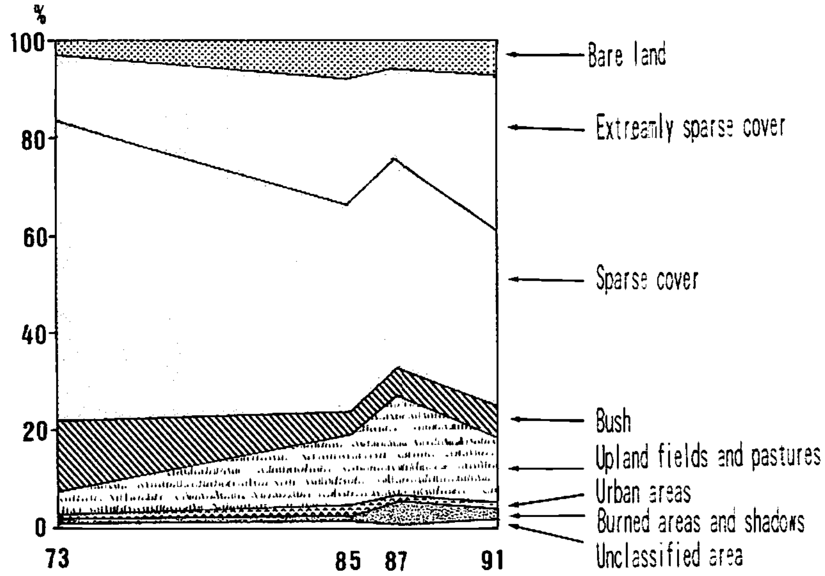

Fig. 3 Inter-annual variations of land cover

tive of this type of land cover. Their color ranges from brown to deep green in the composite image.

(6) Urban areas: Urban areas including Maroua are covered with green leaves of bead trees that line the streets. These areas are easily distinguished from areas covered with natural vegetation, since the latter have no green leaves during the dry season. In the composite image, urban areas appear in red.

(7) Burned areas and shadows: Both burned areas and shadows appear in black in the composite image. Shadows are recognized on the western slopes of the inselbergs, while burned areas often appear in the southern part. The burned areas on the inselberg behind Maroua which were burnt either for pasture or due to accidental fire in the 1987 image are quite conspicuous.

The land cover conditions in the four images were classified by the maximum likelihood method into 21 to 25 categories. The significance of each of these categories was corroborated on the basis of visual interpretations of the composite image, vegetation vigor, and vegetation and soil indices. As a result, the categories belonged to any one of the above seven types, which were then used to draw a map showing the classifications of land cover. Then, to determine the inter-annual variations as shown in Fig. 3, the proportion of the areas of each type of land cover was calculated using the number of pixels for each type.

The land cover conditions for each year are described below:

<1973>: Areas with sparse vegetation cover were distributed throughout the study area. Areas with extremely sparse vegetation cover appeared only along river courses. Bare land was conspicuous around inselbergs in the northwestern region and around the inselbergs lying between Maroua and Bogo. In addition, marks of burning were recognized sporadically in some parts of the southern bush, showing the commence-

ment of the destruction of natural vegetation.

<1985>: In addition to the bare land observed in 1973, new bare land areas appeared over a wide area in the northern half of the study area. In this year, the bare land areas appeared not only around inselbergs but also in the alluvial plain along river courses and in the depressions between inselbergs. The southern bush, present in 1973 had almost completely disappeared. The urban areas of Maroua were apparently more developed along the Tsanaga River than in 1973.

<1987>: Bare land areas expanded along inselbergs in the northwestern region, but diminished to 1973 levels in other regions. On the other hand, most parts of the areas along river courses, including those along the Tsanaga River, were classified as upland fields and pastures. In addition, areas with extremely sparse plant cover appeared in and around the bare land of 1985.

<1991>: Areas with extremely sparse plant cover expanded throughout the study area. Bare land areas also expanded markedly; however, unlike the case with 1985, they expanded mainly in the alluvial plains and the depressions in the eastern half of the study area. The areas along river courses were classified as upland fields and pastures.

Next, the inter-annual variations of land cover conditions during the period 1973 to 1991 were examined on the basis of Fig. 3. A comparison between the 1973 and 1991 images shows that the proportion of the natural vegetation areas as a whole, *i.e.*, from the bare land at the top down to the bush in the lower part in Figure 3, decreased by only about 10 %. However, the proportion of the areas with extremely sparse vegetation cover increased from 14 % to 32 %, revealing the retrogression of vegetation cover density. This tendency is given support by the expansion of bare land areas from 3 % to 7 %, as well as the decrease in bush areas from 14 % to 7 %.

Accordingly, the initial land cover conditions of the areas classified as sparse plant cover, extremely sparse plant cover, or bare land in the 1991 image were traced using the 1973 image. As a result, some parts of the areas classified as sparse vegetation cover in the 1991 image included bush, pastures and burned areas from the 1973 image; extremely sparse vegetation cover of 1991 included sparse plant cover of 1973; and bare land of 1991 included extremely sparse plant cover or sparse plant cover of 1973. Specifically, it was revealed that the plant cover conditions in these areas had deteriorated by one or two ranks.

On the other hand, the proportion of upland field and pasture areas and that of urban areas increased from 6 % to 13 % and from 0.1 % to 1.8 %, respectively, suggesting a steady increase in human activities on these areas.

The results of the 1985 and 1987 image analysis were added to the study of inter-annual variations. It is worth noting that the deterioration of natural vegetation shown by the expansion of bare land and the decrease in vegetation cover density did not progress unconditionally after 1973; rather, it showed the opposite tendency between 1985 when the study area suffered from a severe drought and 1987. In addition, the drastic increase in the proportion of upland fields, pastures and urban areas from 1973 to 1985 suggests a swell in population during these years.

Therefore, the deterioration of vegetation cover since 1973 must be studied with due consideration to influences of human activity in addition to decrease in precipitation since the 1980s.

5. Retrogression Process of Vegetation Cover

Influence of precipitation

The most influential factor governing the amount of vegetation cover in semi-arid areas is precipitation. In particular, the 5-month-long dry season and rainfall patterns that fluctuate greatly in time and space greatly affect the poor vegetation in semi-arid areas. Therefore, the fluctuation of precipitation was studied using precipitation data of Maroua gauged during the past 40 years (Fig. 4). It must be noted that data for Guidiguis, located about 60 km southeast of Maroua, were used for the period between 1979 and 1985, since no observation data for Maroua were available for the period between 1973 and 1985.

The annual precipitation had roughly been at least 800 mm until 1973; however, it decreased to between 600 mm and 700 mm after 1980. In other words, the precipitation in this study area has been decreasing, thus aggravating the retrogression of vegetation cover. In particular, the precipitation gauged immediately before February 1985, when the 1985 image, in which deterioration of vegetation cover was the most noticeable among the four images, was taken, was 651 mm in 1983 and 608 mm in

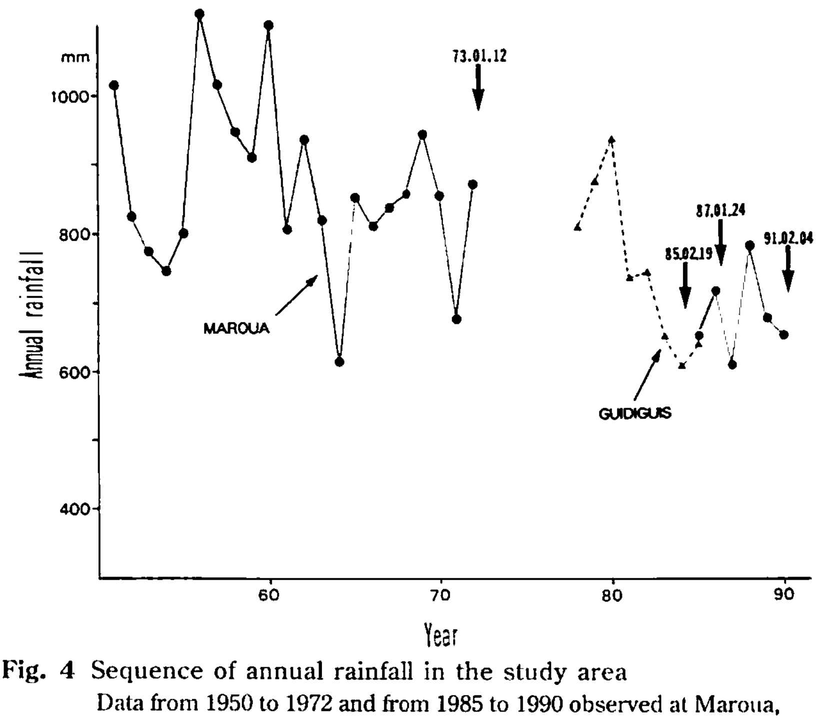

Fig. 4 Sequence of annual rainfall in the study area
Data from 1950 to 1972 and from 1985 to 1990 observed at Maroua, data from 1987 to 1985 observed at Guidigusi, and there is no data in the study area from 1973 to 1977.

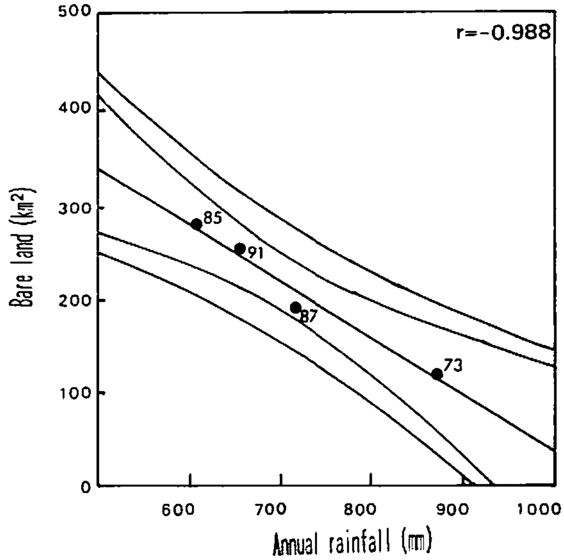

Fig. 5 Relationship between annual rainfall and area of bare land

1984, the lowest since 1951. This coincides with the time when the study area was stricken by a severe drought.

The drought continued in 1985 (641 mm); however precipitation recovered somewhat in 1986 to 718 mm in Maroua and 976 mm in Guidiguis. A comparative study of the images of 1985 and 1987 shows that it is more appropriate to conclude that the slight recovery of vegetation cover conditions was attributable to this recovery of precipitation rather than to changes in population pressures.

Precipitation took a downward turn thereafter, decreasing to 655 mm in 1990. As a result, the vegetation cover conditions in 1991 became as poor as those in 1985.

As discussed so far, the fluctuation of precipitation and the changes of vegetation cover conditions correspond fairly well with each other, proving unequivocally that the amount of vegetation cover of this area is dependent upon precipitation. Therefore, the bare land areas where vegetation cover can be estimated accurately were extracted and compared with the annual precipitation (Fig. 5). The annual precipitation in Fig. 5 is the data gauged one year before the respective image observation years. This is because, in January and February, when the satellite images were taken, the plant cover is undeniably dependent upon the precipitation of the previous year, since the rainfall of this study area falls mainly from April to October. As shown in Fig. 5, it is quite interesting that there is a high correlation between the area of bare land and the annual precipitation for the four years of image data observation.

Possibility for identifying "desertifying" areas

The expansion of bare land in this study area, where the vegetation was originally either steppe or savanna, is proof of a decline in the productivity of land. The emergence of such bare land affects the food production of this area. The problem is not serious with areas where the vegetation cover may return with the recovery of precipitation after a temporary decline. as is the case discussed before. The problem is with so-called "desertifying" areas where irreversible deterioration occurs, *i.e.*, land where plant cover never recovers once it turns into bare land.

Therefore, it was examined whether or not such an irreversible phenomenon had been triggered in the study area by the severe drought of 1983 to 1985. An area of about 416 km^2 that was not bare land in 1973 but became bare land in 1985 was extracted and possible ways in which its land cover conditions had changed by 1987 were investigated (Fig. 6). As a result, about 70 % of the area, which had become bare land between 1973 and 1985, turned into either areas with sparse plant cover, upland fields or pastures, showing that plant cover was somewhat recovering. However, about 25 % of the area remained as bare land in 1987, suggesting that the land was devastated without any sign of plant cover recovery.

Such devastated areas were distributed chiefly in the northwestern region and the region between Maroua and Bogo. They lie between the edges of pediments surrounding inselbergs and slopes going down to river courses. One plausible reason for such areas to remain as bare land may be that the land is more prone to erode when rain falls due to the steep inclination, unlike alluvial plains along river courses that are more level.

It is quite noteworthy that there is a possibility for estimating the productivity of land by clarifying its hysteresis of vegetation cover. This can be done by comparing data of the same area acquired in different years.

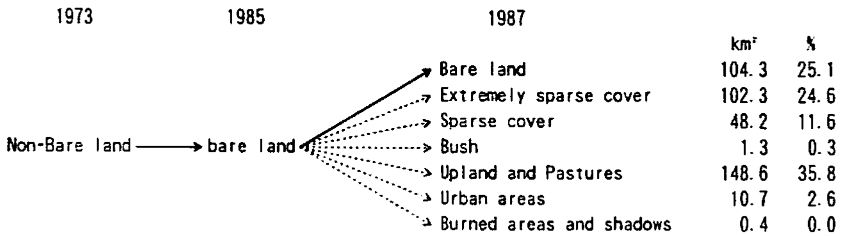

Fig. 6 Land degradation processes of the study area between 1973 and 1987

6. Conclusion

In this study, bare land, pastures, dense shrub forests, trees with leaves. and burned areas were successfully classified and the inter-annual variations of land cover of this study area were clarified using data observed during the dry season. In addition, a possible way to monitor land degradation was suggested.

It appears that there is a positive correlation between plant cover and precipitation. However, it is certain that the study area in recent years has also been affected by steady population growth, shrub cutting for firewood, and pasturage of goats and sheep. During the field surveys, street vendors selling firewood and charcoal materials and groups of shrubs cut down to waist height were seen here and there along major roads. Herds of goats and sheep were often spotted migrating from place to place where there was almost no grass but clouds of sand being blown up. These facts suggest that it is difficult to give an explanation to the retrogression of vegetation cover of this area only by the fluctuation of precipitation, and that evaluating the effects of human activities is a topic for future studies.

The authors intend to apply the analysis conducted in this study to a wider range of studies and to further examine the results obtained herein to learn through image analysis whether the recent vegetation cover retrogression can be attributed to either the decrease in precipitation or to human activities.

Acknowledgments

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